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Recovery of Aromatics from Pyrolysis Gasoline by Conventional and Energy-Integrated Extractive Distillation

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Abstract

Extractive distillation is widely used technology for recovering aromatics from different feedstock. This study investigates the recovery of aromatics which has an important commercial application such as benzene, toluene and xylenes from pyrolysis gasoline using a solvent called N-methylpyrolidone. The study also examines the procedures involved in implementing the energy-integrated extractive distillation technologies such as Petlyuk column, divided wall column and heat integrated extractive distillation column compared to conventional extractive distillation technique for processing petrochemical cuts in the range of C_5 to C_9. Design, modeling and simulation have been conducted for the examined extractive distillation configurations and the optimum design is selected based on minimum total annual cost as the objective function. Different solvent (S)/feed (F) ratios (2/2.5/3 vol%) have been investigated to reach the optimum separating ratio, the effect of solvent feed temperature is considered also. The designed extractive distillation columns meet all expectations regarding energy consumption and cuts purity. The economic analysis proved that heat-integrated configurations are the best candidates compared to Petlyuk column and divided-wall column. Solvent feed ratio of 2 vol % found to be the best from energy and material consumption point of view, reducing solvent temperature is improving extraction process and reducing the reflux ratio of extractive column.

Keywords: pyrolysis gasoline, energy-integrated extractive distillation, N-methylpyrolidone

1. Introduction

The aromatic components come from the catalytic reformer or steam cracker pyrolysis gasoline is found with other close-boiling hydrocarbons, some of which form azeotropes with the aromatics. This makes it impossible to separate pure aromatics by classical distillation; the use of a solvent in distillation to enhance the separation efficiency is recognized throughout the academic world as a useful means to separate close-boiling mixtures. The aromatics can be purified using selective solvents that have a differential attraction to the aromatic ringed compounds. There has been an ever-increasing demand for a higher purity of aromatics as a feedstock for chemical synthesis, many solvents such as Sulfolane [1-2], N-methylpyrolidone (NMP) [3], and N-formulmorpholine (NFM) [4-5] are used to extract aromatics such as benzene, toluene and xylene from hydrocarbon mixtures. The NMP extractive distillation process separates aromatics from pyrolysis gasoline and refines the extracted aromatics, which are used as raw materials of petrochemical processes. The initial equipment cost and the operating cost for the whole plant can be reduced by the decision of the optimum solvent/feed ratio, and also by applying energy integrated techniques. Thermally coupled extractive distillation (Petlyuk column or DWC) has been investigated and proved its potential of saving in both capital and operating costs [6]. The purpose of this work is to investigate the economic potential of conventional two-column ED with backward heat integration comparing with the design of conventional two-column ED configuration and thermally coupled ED configuration (Petlyuk column) and studying the effect of solvent feed ratios on the energy consumption and saving of the studied configurations.

2. A case study

Aromatic recovery via extractive distillation is accomplished in two distillation towers, the first is an extractive distillation column, where the separation of the feed components occurs; and the second column is a solvent recovery column (stripper column) where the solvent is separated from the desired product. This study is intended towards recovery of aromatics from pyrolysis gasoline by extractive distillation using NMP as a solvent. Different extractive distillation techniques has been investigated and evaluated rigorously based on total annual cost minimization as the economic objective function. The studied pyrolysis gasoline stream is a mixture of three cuts C_5 cut (142 kgmol/hr), C_6-C_8 cut (366 kgmol/hr) and C_9 cut (21.02 kgmol/hr). The feed cuts are mixed together in mixing tank and fed to the extractive distillation column as liquid at bubble point. Solvent/feed ratios are optimized for maximum aromatic recovery and minimum energy consumptions. The feed mixture contains 30 components C_5 cut is mostly cyclopentene and cyclopentane, $C_{6\text{-}8}$ cut is mostly benzene, toluene and mixed xylenes, and C_9 cut is mostly n-nonane.

3. Studied extractive distillation configurations

Three extractive distillation (ED) configurations are investigated in this study, the first one is conventional two-column arrangement Figure 1, the hydrocarbon mixture is introduced to the first column (extractive distillation column) where the low-boiling fraction non-aromatic is recovered as the top product.

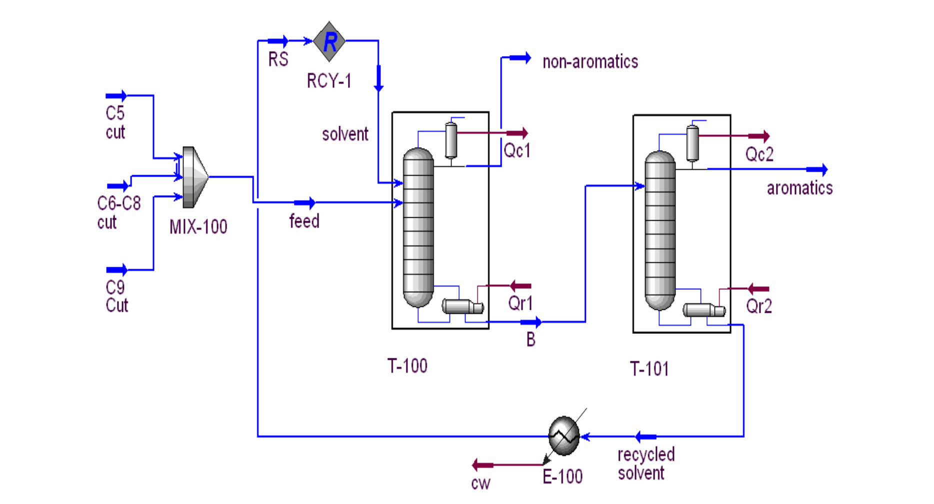

Figure 1. Conventional two-column ED

The bottom product is fed to the second column (stripper column) where the medium boiling fraction aromatics is distilled off as the top product and the high boiling fraction solvent remains as the bottom product and is recycled to the extractive distillation column. The second arrangement is the thermally coupled column (Petlyuk column) as shown in Figure 2, where the medium boiling fraction aromatics accumulates in the main column and is drawn as a side product. Compared to the previously mentioned configuration, this arrangement requires only one heating and condensing device for both columns. In addition, the thermodynamic advantages of this arrangement over conventional distillation, which result in lower energy requirements, have long been known [6].

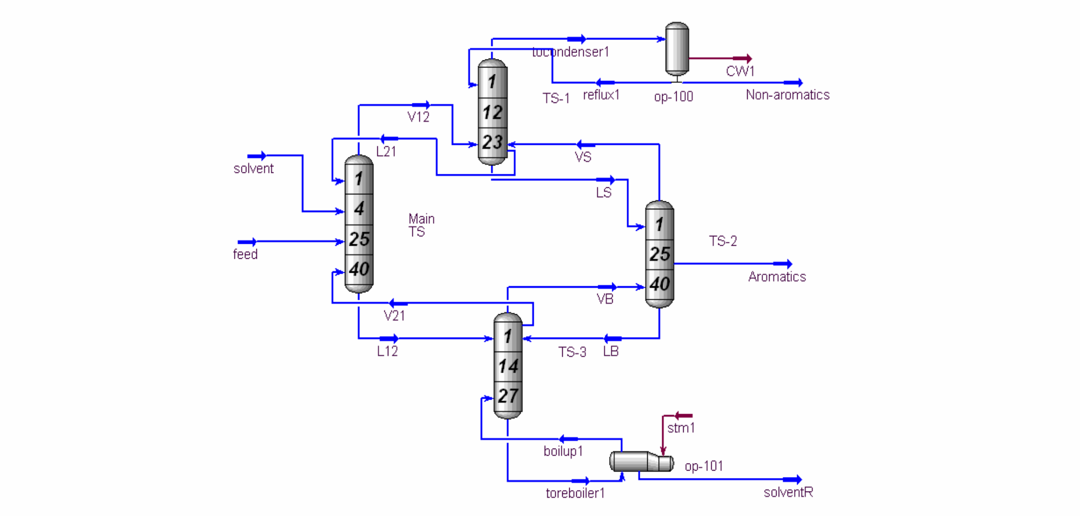

Figure 2. Petlyuk column (DWC)

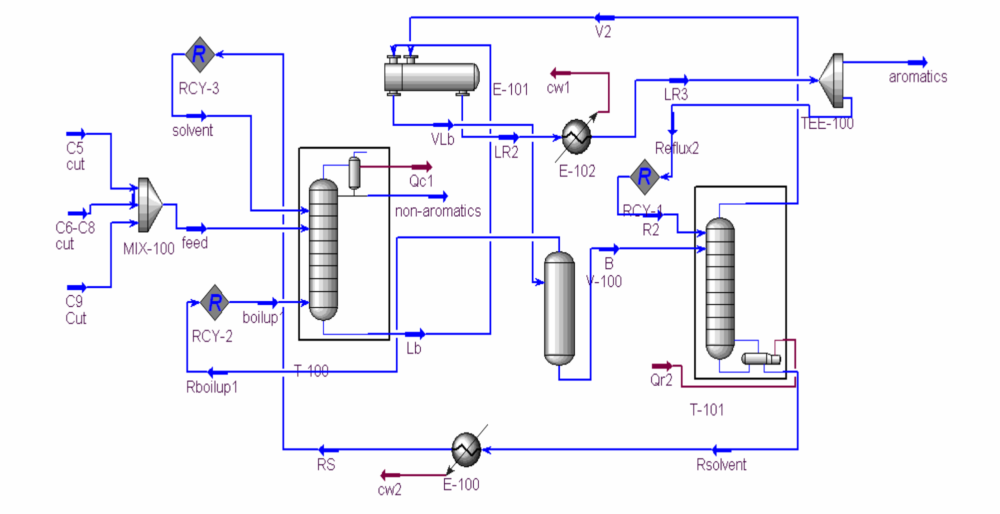

Figure 3. Conventional ED with backward heat integration

A further development of the Petlyuk column is to incorporate the side column in the main column, thus resulting in considerably lower investment costs. This arrangement is referred to as the divided-wall column. The energy requirements and the concentration profiles of the Petlyuk column and the divided-wall column are completely identical. Similarly the possibility of simplifying and cost-optimizing the extractive distillation process through the application of a one shell column arrangement is being investigated [6]. The third investigated arrangement is conventional ED with backward heat integration as shown in Figure 3 and it is based on the idea of utilizing the overhead vapors of the stripper column to provide heat content for boiling up the extractive distillation column and in this case the stripper column is operated at higher pressure compared to extractive distillation column.

3.1. Optimization technique

The ED configurations are simulated rigorously using HYSYS simulator based on maximum recovery of aromatics from the feed stream and minimum benzene content in the non-aromatics product stream due to environmental regulations. The capital and operating cost for the ED configuration is conducted based on certain cost correlations [7]. For each distillation configuration, the number of trays, feed location, solvent feed location, solvent/feed ratio and solvent temperature are considered as optimization variables. A number of specifications are kept as constraints in order to achieve the optimal design structure in the studied configurations, these constraints represented by; the recycled solvent purity is equal to 99.99 % molar concentration, the amount of n-hexane and 1-hexene at non-aromatic stream never exceed 0.002 mol %, and total amount of benzene, toluene and xylenes enter the stripper column are recovered in aromatics stream.

3.2. Optimization results

The results of rigorous optimization are collected in Tables 1 and 2 for the three different extractive distillation configuration indicating the effect of solvent feed ratio (S/F) on the economic evaluation of the studied extractive distillation configurations at solvent temperature of 60 °C. The results can be summarized as follows: (i) Reducing solvent feed ratio of the extractive distillation systems causes a reduction of energy consumption of the extractive distillation configurations and consequently the total annual cost savings will be reduced as shown in Table 1, (ii) the maximum TAC savings achieved by Petlyuk column is 19.1 %, and (iii) conventional ED with backward heat integration prove to be the best regarding energy consumption and TAC savings with 20.3 % compared to conventional ED configuration as shown in Table 2. The savings of conventional ED with backward heat integration is expected to increase with increasing of solvent feed ratio. Reducing the solvent temperature to 40 °C is further improving the energy consumption of the studied configurations.

Table 1. Optimization results of ED configurations at different solvent feed ratios

Specifications	S/F = 3.0				S/F = 2.5			
	Conventional ED		Petlyuk column		Conventional ED		Petlyuk column	
	Col.1	Col.2	Col.1	Col.2	Col.1	Col.2	Col.1	Col.2
Theoretical trays	72	60	40	90	72	60	40	90
Diameter (m)	3.3	3.0	2.5	3.2	3.0	2.7	2.3	3.0
Duty (KJ/hr)*10^7	10.24		6.44		8.67		5.52	
TAC (M$/Year)	10.14		8.20		8.55		7.06	
TAC saving %	0.00		19.1		0.00		17.43	

Table 2. Optimization results of ED configurations at S/F = 2.0

Specifications	Conventional ED		Petlyuk column		Conventional heat-integrated ED	
	column1	column2	column1	column2	column1	column2
Theoretical trays	72	60	40	90	53	100
Diameter (m)	2.8	2.5	2.2	2.8	2.4	2.2
Duty (KJ/hr)*10^7	7.23		4.84		4.38	
TAC (M$/Year)	7.14		6.21		5.69	
TAC saving %	0.00		13		20.3	

4. Conclusions

A general rule governing the ranking and saving of the studied ED configurations according to solvent feed ratio is the increasing of heat duty requirement with increasing solvent feed ratio. The TAC saving of the ED configurations increases with increasing the amount of heat loads which has to be recycled between the columns. The economic potential of conventional ED with backward heat integration is proved to be superior with maximum savings of 20.3 %.

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